EXHAUST HEAT RECOVERY SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to an exhaust heat recovery system for recovering heat exhausted from a condenser in steam turbine facilities, such as thermal power plants and light-water reactor power plants, by operating a compression-type heat pump utilizing carbon dioxide as a refrigerant.

In the thermal power plant, light-water reactor power plant or other steam turbine facilities, typically, the heat of water that has been heated and boiled in the boiler (in the case with the light-water reactor, the core of the boiling water reactor or the steam generator of the pressurized water reactor) is used to drive the steam turbine to generate electric power; the steam used to drive the steam turbine is then subjected to cooling by ocean water or air, and condenses into liquid water, which is recycled as feed water to the boiler.

For example, FIG. 4 is a system diagram showing a conventional steam turbine facility. In this steam turbine facility 20, steam obtained by heating and boiling water in a boiler 21 is led into a turbine 22, and then expanded steam is cooled in a condenser 23 with the ocean water or air as a cooling medium and is condensed into liquid water, which is fed back to the boiler 21 as feed water by a feed pump 24, so that a recirculation channel of water is formed therein. The cooling medium such as ocean water or air used to cool the expanded steam in the condenser 23 is thereafter discharged into the ocean or air.

Taking a power plant as an illustration of a steam turbine facility for discussion, the electric power generation efficiency is approximately 53% in the state-of-the-art combined-cycle thermal power plant, and approximately 34% in the state-of-the-art

light-water reactor. This demonstrates that approximately half to approximately two thirds of the heat generated in either of these power plants is lost as warm drainage water discharged into the ocean or the like, and is thus not utilized in an energy-efficient manner, entailing a disadvantage in economy of fuel resources, while posing a problem of effluent warm drainage water potentially damaging surrounding environments.

While ocean water as an example of the cooling medium discharged from the condenser is given only about 7°C rise in temperature relative to that before it is led into the condenser, the recovery of waste heat from the cooling medium to be discharged entails enormous cost. Therefore, the utilization of the waste heat is achieved at present only in a limited range of applications such as farming fisheries.

In view of the circumstances as above, Japanese Laid-Open Patent Application, Publication No. 5-296009 (JP 5-296009 A) proposes an exhaust heat recovery system in which cooling water for a steam turbine condenser is used, to be more specific, passed through an evaporator provided in an absorption chiller, to make warm water for heating purposes.

The heat recovery system disclosed in JP 5-296009 A, however, has disadvantages as described below.

In the heat recovery system disclosed in JP 5-296009 A, the absorption chiller is employed to generate warm water. However, the absorption chiller requires another working medium, that is, an absorbent solution, in addition to the refrigerant. Further required, in addition to the evaporator, are an absorber, a regenerator, and if more improved thermal efficiency is desired, a high-temperature regenerator. The multitude of these elements required additionally as recited above likely leads to undesired upsizing of the system. Moreover, the absorber of the absorption chiller which has to permit a heat exchange, material exchange and phase change to simultaneously take

place inside between the absorbent solution and the refrigerant/cooling water; thus, the complexity in the construction of the absorber and the resulting limitation placed on miniaturization thereof would pose a problem.

Various combinations of the absorbent solution and the refrigerant are used at present, among which two well-known combinations are: a lithium bromide/water system and a water/ammonia system. It is known that lithium bromide absorbent solutions have a corrosive nature to iron or the like and ammonia refrigerants have a corrosive nature to copper, and thus the treatment of the corrosive nature always presents a serious challenge in the technical field of the absorption chiller. Further, multifarious restrictions are imposed on properties (conditions for crystallization) of the absorbent solution and other conditions such as of chilled water, cooling water and warm water used during operation in the absorption chiller, which disadvantageously makes an operation management thereof laborious.

Furthermore, the exhaust heat recovery system as disclosed in JP 5-296009 A is provided with a cooling water channel, through which water or the like flows, interposed between the condenser and the evaporator of the absorption chiller; thus, the heat exchange efficiency in the condenser is kept low, and the size of the condenser cannot be made compact any more, which are also perceived as disadvantages thereof.

The present invention has been made in view of the disadvantages associated with prior art as described above.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, there is provided an exhaust heat recovery system in which otherwise wasted heat is directly recovered from a condenser of a steam turbine power plant by a compression type heat pump.

The compression type heat pump uses only a single refrigerant, and thus is simple in construction, compact in size, and efficient in energy consumption. In particular, the heat exchangers of a compression type chiller used herein mostly include only two units, *i.e.*, an evaporator and a condenser, in which a phase change alone takes place; therefore, plate-type exchangers readily available may be adopted, and reductions in size can easily be achieved. Since few refrigerants therefor has a corrosive nature to iron, inexpensive materials of iron can be employed without special care; accordingly, with consideration given to specific metal materials, the treatment of the corrosive nature can be carried out with relative ease. For the reasons as discussed above, fabrication of the system is easier, and the operation management is easier, in comparison with the instances where an absorption chiller is adopted.

Moreover, the condenser permits a heat exchange process to proceed immediately between a refrigerant and steam which is going to condense into liquid water, without any heating medium such as cooling water interposed. Accordingly, in comparison with the instances where cooling water or other heating medium is used for a heat exchange process, a loss of heat is kept smaller, so that energy dissipation can be minimized.

Preferably, carbon dioxide may be used as a refrigerant for the compression type heat pump.

Chlorofluorocarbon (CFC), etc. formerly used widely in the compression type heat pumps have been driven out of practical applications due to serious concern

widespread in recent years about an environmental load thereof. On the other hand, ammonia, which has become a focus of attention as an alternative refrigerant, possesses toxicity and emits distinctive foul smell, and thus cannot be used without difficulty or care.

TABLE 1 shows exemplary refrigerants for use in the compression type heat pump.

TABLE 1

NAME OF REFRIGERANT	GLOBAL WARMING POTENTIAL	TOXICITY	COMBUSTIBILITY	COP*
Carbon dioxide	1	No	No	Equal
Ammonia	0	Yes	Low	Equal or higher
Air	0	No	No	Lower
Propane	3	No	Low	Equal or higher
CFC Substitute R407C	1500	No	No	Equal
CFC Substitute R410C	1700	No	No	Equal
Currently unprohibited CFC (HCFC)	1700	No	No	Equal

* Coefficient of Performance: comparison made with HCFC

Source: Material from Central Research Institute of Electric Power Industry

As shown in TABLE 1, carbon dioxide is nontoxic and lower in environmental load than other refrigerants, and may therefore be deemed to be an ideal refrigerant. In addition, the CFC and substitutes thereof have high critical temperatures approximate to 100°C, and thus the temperature of warm water should not be higher than 65°C or so in view of energy efficiency; in contrast, carbon dioxide having critical temperature of approximately 31°C can be supplied with warm water of approximately 90°C in temperature. Accordingly, high-efficiency energy transport can be achieved using warm water generated in the exhaust heat recovery system. Moreover, thus-generated warm water exhibits high temperature, and the warm water

can be supplied stably; therefore, the warm water can be utilized not only for heating but also for local air conditioning.

As described above, the use of carbon dioxide as a refrigerant for a compression type heat pump makes it possible to provide an exhaust heat recovery system which imposes reduced loads on the environment and can thus be used for various applications.

Further, the above exhaust heat recovery system may preferably utilize boiling heat transfer having high heat-removing performance for heat recovery from the condenser.

It is known that the boiling heat transfer uses latent heat of vaporization and thus exhibits high efficiency in heat transfer. Therefore, the utilization of such boiling heat transfer for heat exchange in the condenser serves to achieve high-efficiency heat exchange, as well as miniaturization of the condenser.

According to the present invention as described above, in a condenser of a steam turbine facility which uses steam to spin a turbine and produce a power, exhaust heat generated therein is directly recovered by means of a compression type heat pump to obtain warm water. The use of thus-obtained warm water serves to utilize heat which would conventionally be wasted in the steam turbine facility. Consequently, an exhaust heat recovery system for making an effective use of waste heat is provided in a compact body with easy operation management.

Other advantages and further features of the present invention will become readily apparent from the following description of preferred embodiments with reference to accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a system diagram of an exhaust recovery system.

FIG. 2 shows a pressure-enthalpy chart for illustrating a refrigeration cycle of a compression type heat pump.

FIG. 3 shows a graph for illustrating a heat transfer area rate versus temperature of a refrigerant to be led into a condenser.

FIG. 4 shows a system diagram of a conventional steam turbine facility.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A detailed description of a preferred embodiment will be given hereinafter with reference to the accompanied drawings. It is however to be understood that the present invention is not confined, unless explicitly specified, to a specific illustration of the dimensions, materials, shapes of each component and relative arrangement thereof according to this exemplary embodiment, and any modifications and changes may be made within the scope of the present invention as a matter of course.

To illustrate the present embodiment, reference is made to FIG. 1 in which a system diagram of an exhaust heat recovery system of a steam turbine facility is represented.

The exhaust heat recovery system as shown in FIG. 1 may be discussed separately in two portions: a steam turbine power plant unit 1 for generating electric power by using a steam turbine, and a heat pump unit 2 for generating warm water by utilizing heat otherwise dissipated in a condenser 6 of the steam turbine power plant unit 1.

The steam turbine power plant unit 1 includes a boiler 3, a generator 4, a turbine 5 connected with the generator 4, a condenser 6, and a feed pump 7, whereas the condenser 6 and the feed pump 7 are cascaded between an outlet of the turbine 5 and an inlet of the boiler 3.

The heat pump unit 2 that forms the heart of the present invention includes a compressor 8, a gas cooler 9 for allowing a heat exchange to take place between refrigerant and warm water produced in a load, and an expander 10. In the present embodiment, carbon dioxide is used as a refrigerant for the heat pump 2, and an outlet side passage of the expander 10 is connected to an inlet end of a heat pipe of the condenser 6, while an outlet end of the heat pipe is in turn connected to an inlet of the compressor 8.

Accordingly, carbon dioxide as a refrigerant, which has been evaporated in the condenser 6 during heat exchange between the refrigerant and the steam led from the turbine 5, is sucked and compressed in the compressor 8 and then cooled in the gas cooler 9 through heat exchange with warm water produced in the load; the cooled carbon dioxide is led into the expander 10, expanded/liquefied therein, and then returned to the condenser 6 for undergoing another cooling process. Thus, a heat-pump operation cycle is performed repeatedly. As described above, in the condenser 6, gaseous carbon dioxide (refrigerant) generated by boiling is directly utilized as a medium of heat exchange for the compression type heat pump, so that a simplified construction of the system and efficient heat recovery can be achieved.

Next, a description will be given of an operation of an exhaust gas recovery system according to the present embodiment as shown in FIG. 1. To illustrate an operation of a steam turbine power plant unit 1, first, steam heated in the boiler 3 is led into the turbine 5, to turn the turbine 5 and thereby drive the generator 4. Steam used to drive the generator is then expanded (at a temperature of approximately 33°C,

under a pressure of approximately 96.3KPa in the condenser) and discharged into the condenser 6, and condensed in the condenser 6 to liquid water at a saturation temperature (at a temperature of approximately 33°C, under a pressure of approximately 96.3KPa in the condenser). Thereafter, the water condensed in the condenser 6 is fed by the feed pump 7 again to the boiler 3, as feed water for generating steam.

Exhaust heat of the condenser 6 generated to condense steam led from the turbine 5 into liquid water is recovered by the heat pump unit 2 connected with the condenser 6, using a compression type heat pump.

Subsequently, an operation of the heat pump 2 will be described in detail with reference to FIGs. 1 and 2. Hereupon, FIG. 2 shows an exemplary pressure-enthalpy (P-h) chart of carbon dioxide for representing a refrigeration cycle of a compression type heat pump according to the present embodiment, on coordinates of pressure P against enthalpy h. In the following discussions, reference characters A, B, C and D denote the conditions (temperature and pressure) of carbon dioxide as a refrigerant for the compression type heat pump; *i.e.*, reference characters A, B, C and D of the heat pump unit 2 used in FIG. 1 correspond to these reference characters A, B, C and D of P-h chart of FIG. 2 to show that each portion of the heat pump unit 2 is under the condition (temperature and pressure) defined in FIG. 2 by the corresponding reference character.

First, steam discharged from the turbine 5 and led into the condenser 6 undergoes heat exchange with liquid carbon dioxide (*e.g.*, A: approximately 20°C; 5.7MPa) in a heat exchanger (not shown) provided in the condenser 6, so that the steam is cooled to condense into liquid water.

At this stage, the refrigerant carbon dioxide obtains heat from steam in the condenser 6, and boils, changing a condition thereof (B: approximately 25°C; 5.7MPa),

with the result that phase change occurs in the carbon dioxide from a liquid state to a gaseous state (point A to point B).

Next, the gaseous carbon dioxide (B: approximately 25°C; 5.7MPa) is compressed in the compressor 8, with a temperature thereof raised (point B to point C), and changed into gaseous carbon dioxide at a temperature of approximately 90°C (point C: approximately 90°C; 12MPa). This carbon dioxide with its temperature raised accordingly (point C: approximately 90°C; 12MPa) is led into the gas cooler 9 to undergo heat exchange in a heat exchanger (not shown) provided in the gas cooler 9 with warm water produced in the load, and thereby cooled to approximately 30°C (point C to point D, where point D: approximately 30°C; approximately 12MPa).

On the other hand, the temperature of the warm water produced in the load is raised in the gas cooler 9 from approximately 25°C at an inlet thereof to approximately 80°C at an outlet thereof. The warm water having a temperature raised as such is utilized: as hot water for heating at home, in business office buildings, or in the factories; as heat source for heated swimming pool; or as heat source hot water for local air conditioning.

The refrigerant carbon dioxide resultantly having a temperature of approximately 30°C in the gas cooler 9 (point D: approximately 30°C; approximately 12MPa) is decompressed in the expander 10 from approximately 12MPa to approximately 5.7MPa, and is thereby cooled to approximately 20°C, so as to condense into liquid carbon dioxide (point D to point A, where point A: approximately 20°C; 5.7MPa). This liquid carbon dioxide (point A: approximately 20°C; 5.7MPa) is recycled as a cooling medium for the condenser 6.

From the foregoing, it is shown that the heat recovery by means of the compression type heat pump makes it possible to effectively utilize, as warm water,

exhaust heat which would be dissipated into the ocean or the air through the condenser according to a conventional steam turbine facility.

Further, since heat is removed by using latent heat of vaporization of the refrigerant for the compression type heat pump according to the present embodiment, boiling heat transfer having high heat-transfer performance can be used, and thus the condenser 6 can be designed to be smaller in size. Referring now to FIG. 3, in which heat transfer area rates versus temperatures of refrigerant to be led into the condenser are plotted, for example, it is graphically shown that the heat transfer area of the condenser required for cooling with liquid carbon dioxide is about one-half of the heat transfer area of the condenser required for cooling with ocean water when compared with respect to each reference temperature of the refrigerant.

Moreover, the use of carbon dioxide as a refrigerant is toxicologically safe as described above, and CFC-free. The CFC and substitutes thereof have high critical temperatures of approximately 100°C, and thus the temperature of warm water should not be higher than 65°C or so in view of energy consumption efficiency; in contrast, carbon dioxide having critical temperature of approximately 31°C can be supplied with warm water of approximately 80°C in temperature, which warm water can also be utilized as a heat source for local air conditioning.

According to the present invention which may be embodied with the above construction and which may be operated as discussed above, advantageous effects can be achieved as follows:

Exhaust heat which would be released through a condenser into the ocean or the air in the conventional steam turbine facility can be utilized effectively, and carbon dioxide can be reduced by the amount of heat recovered, thereby contributing to the global warming prevention.

The use of a compression type heat pump for the exhaust heat recovery system allows the whole facility to be made smaller in size than those using an absorption chiller, and the operation management thereof to be made easier.

The use of carbon dioxide as a refrigerant for the compression type heat pump makes it possible to reduce environmental loads, and to produce high-temperature warm water, which can be utilized for a wide range of applications.

The use of boiling heat transfer, which exhibits high heat-exchange efficiency, for heat exchange in the condenser makes it possible to provide a condenser that is highly efficient in heat exchange and compact in size.

Direct heat exchange with a refrigerant carbon dioxide carried out in the condenser without using cooling water obviates the need for a conventionally required cooling medium such as ocean water, etc., so that the exhaust heat recovery system can be installed inland, underground or otherwise where cooling water is unprocurable.